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RESEARCH MEMORANDUM

TESTS OF A TRIANGULAR WING OF ASPECT RATIO 2 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. III - THE EFFECTIVENESS AND HINGE MOMENTS OF A SKEWED WING-TIP FLAP

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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TESTS OF A TRIANGULAR WING OF ASPECT RATIO 2 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. III - THE EFFECTIVENESS AND HINGE MOMENTS OF A SKEWED WING-TIP FLAP

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SUMMARY

A semispan model of a triangular wing equipped with a skewed wing-tip flap was tested to evaluate the effectiveness and hinge-moment characteristics of this form of control surface up to a Mach number of 0.95.

Lift, drag, pitching-moment, and hinge-moment data are presented for Mach numbers from 0.30 to 0.95 at a constant Reynolds number of 3,200,000. Similar data are presented for a Mach number of 0.18 at a Reynolds number of 5,000,000.

The data indicate that the effectiveness of the flap was low at all speeds. An increase in Mach number from 0.30 to 0.95 improved the lift effectiveness of the flap by 20 percent and the pitching-moment effectiveness by 40 percent.

The rate of change of the hinge-moment coefficient with angle of attack was large and negative and changed from -0.029 to -0.040 as the Mach number was increased from 0.30 to 0.95. For the same range of Mach numbers, the rate of change of the hinge-moment coefficient with flap deflection increased negatively from -0.008 to -0.010.

When applied to a hypothetical airplane, the skewed wing-tip flap is shown to require flap deflections and hinge moments several times greater to maintain level flight than does a constant-chord flap.

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INTRODUCTION

Wings of triangular plan form, combining the structural advantages of low aspect ratio and high taper ratio with the aerodynamic benefits of a highly swept leading edge, have been shown to be suitable for flight at moderate supersonic speeds. As a part of systematic research on supersonic airplane configurations at the Ames Aeronautical Laboratory, tests are being conducted to evaluate the relative merits of flaps of various plan forms for use as longitudinal controls on triangular wings.

The data presented in reference 1 show adverse compressibility effects on the hinge-moment characteristics of a constant-chord flap having an unswept hinge line. The present series of tests was conducted in the Ames 12-foot pressure wind tunnel to determine if sweeping of the control-surface hinge line would alleviate these compressibility effects. A wing-tip flap with the hinge line swept 63.43° was tested on a semispan model of a triangular wing of aspect ratio 2. Flap effectiveness and hinge moments were measured at Mach numbers up to 0.95.

SYMBOLS

C_D drag coefficient $\left(\frac{\text{drag}}{qS}\right)$

C_h hinge-moment coefficient $\left(\frac{\text{hinge moment}}{qb_f\bar{c}_f^{2}}\right)$

C_L lift coefficient $\left(\frac{\text{lift}}{qS}\right)$

C_m pitching-moment coefficient about the quarter-chord point of the wing mean aerodynamic chord $\left(\frac{\text{pitching moment}}{qSc'}\right)$

M Mach number $\left(\frac{V}{a}\right)$

R Reynolds number $\left(\frac{\rho Vc'}{\mu}\right)$

S wing area, square feet

V airspeed, feet per second

W gross weight of airplane, pounds

W/S wing loading, pounds per square foot

a speed of sound, feet per second

b_f span of the flap measured along the hinge line, feet

$\overline{c}_f$ root-mean-square chord of the flap aft of the hinge line measured perpendicular to the hinge line, feet

c' wing mean aerodynamic chord, M.A.C. (chord through centroid of semispan wing plan form), feet

q dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$, pounds per square foot

α angle of attack of wing chord line, degrees

δ flap deflection measured in a plane perpendicular to the hinge line, degrees

μ viscosity of air, slugs per foot-second

ρ mass density of air, slugs per cubic foot

MODEL

Except for the change in control-surface plan form, the model wing used in this research was the same as that used in the investigations reported in references 1 and 2. The profile was an uncambered double wedge modified by rounding the ridge and the leading edge. This modification changed the aspect ratio slightly as may be seen in figure 1, the value for the complete triangular wing represented by this model being 2.036 instead of 2 as stated by the title of this series of reports. The control surface was triangular in plan form, the hinge line being swept at an angle of 63.43°. The area of the flap aft of the hinge line was 20.45 percent of the wing area. The control surface was attached to the wing by three hinges and was restrained just aft of the point of maximum wing thickness by a flap-angle indexing bracket and strain-gage unit. The flap had a radius nose and an unsealed gap of approximately 0.04 inch.

The semispan model was mounted vertically on a turntable in the flat section of the tunnel floor as shown in figure 2.

CORRECTIONS TO DATA

Corrections have been applied to the data for the effects of tare forces, tunnel-wall interference and constriction. These corrections are the same as those applied to the data for the wing alone in reference 1.

Angular deflection of the flap-angle indexing head under load was known to be appreciable due to the low rigidity of the restraining bracket. The magnitude of this deflection was ascertained from a static loading test of the flap. Since the no-load flap angle was set by means of the indexing head, each test run represents a small range of flap deflections. Data for constant flap angles and constant angles of attack were obtained by interpolating graphically between the test points. Care was taken to preserve any irregularities, so that the uniformity of the test points for any one curve is typical of the uncorrected data. Angular distortion of the flap itself as a result of aerodynamic loading was negligible.

Test data at points where the hinge moment passed through zero may be in error, as the flap was free to move approximately one-half of a degree in either direction from the desired flap setting without the application of load. This freedom was due to the difficulties encountered in the construction of an indexing bracket and strain-gage unit small enough to be contained within the wing.

TESTS

Lift, drag, and pitching-moment characteristics of the model and the hinge-moment characteristics of the flap were measured over an angle-of-attack range for various flap deflections. The data were obtained at a constant Reynolds number of 3,200,000 for Mach numbers ranging from 0.30 to 0.95 and at a constant Reynolds number of 5,000,000 for a Mach number of 0.18. The angle of attack of the model was varied from -10° through 30° for flap deflections from 4° to -26°. At Mach numbers greater than 0.3, the angle-of-attack range was limited by vibration of the flap or by stress limitations of the strain gage.

RESULTS

Data for a range of angles of attack and various flap deflections are presented in figures 3 through 10. In these figures, angle of attack, pitching-moment, hinge-moment, and drag coefficient are presented as a function of lift coefficient for flap angles ranging from 4° to -26°. The data presented in figure 3 were obtained at a constant Reynolds number of 5,000,000 for a Mach number of 0.18.

The data of figures 4 through 10 were obtained at a constant Reynolds number of 3,200,000 for Mach numbers of 0.300, 0.600, 0.800, 0.850, 0.900, 0.925, and 0.950.

DISCUSSION

The data presented in figures 3 through 10 indicate the flap to be effective in producing changes in lift and pitching moment at Mach numbers up to 0.95 for the range of flap deflections. A forward movement of the aerodynamic center occurs at positive angles of attack as the flap is deflected in the direction to decrease the lift. This change in longitudinal stability results in greater variation of pitching-moment coefficient with flap deflection as the angle of attack is increased. The rate of change of hinge-moment coefficient with lift coefficient is a maximum for small values of lift coefficient.

Figure 11 presents the variation of lift-drag ratio with lift coefficient at three Mach numbers, 0.300, 0.800, and 0.925. Since the model was symmetrical about the chord plane, positive flap settings may be represented by reversing the signs of the axes. Reference 1 has shown that small positive deflections of a constant-chord flap resulted in an increase in the lift-drag ratio for Mach numbers less than 0.93; whereas data for the skewed wing-tip flap indicate a reduction in lift-drag ratio when the flap is deflected.

Figure 12 presents the variation of lift, pitching-moment, and hinge-moment coefficient with flap deflection for 0° angle of attack at several Mach numbers. Flap effectiveness and hinge moment are approximately linear at 0° angle of attack for the range of flap deflections. An increase in Mach number caused an increase in the absolute values of the slopes of these curves. The lift effectiveness $\partial C_L/\partial\delta$ and the pitching-moment effectiveness $\partial C_m/\partial\delta$ measured through 0° flap deflection at 0° angle of attack are presented in figure 13 as a function of Mach number. The effectiveness of the constant-chord flap on the same wing (reference 1) is included for comparison. The effectiveness of the skewed wing-tip flap is approximately one-fourth that of the constant-chord flap. The effectiveness of either flap increases with increasing Mach number.

The hinge-moment parameters $\partial C_h/\partial\alpha$ for undeflected flap measured through 0° angle of attack, and $\partial C_h/\partial\delta$ at 0° angle of attack measured through 0° flap deflection are presented in figure 14 as a function of Mach number. Similar data for the constant-chord flap (reference 1) are presented for comparison. The value of $\partial C_h/\partial\delta$ for the skewed wing-tip flap is about one-half the value for the constant-chord flap; whereas the value of $\partial C_h/\partial\alpha$ is more than three times as large for the skewed wing-tip flap as for the constant-chord flap.

The control-surface deflection and the corresponding hinge-moment coefficient required to balance the triangular wing about the 0.25 point of the M.A.C. at various lift coefficients are shown in figure 15 for several Mach numbers. Data are presented for both the skewed wing-tip flap and the constant-chord flap. The comparatively low effectiveness of the skewed wing-tip flap is clearly shown in this figure. It is seen that, for a given control-surface deflection, the constant-chord flap will produce four times as large a balanced lift coefficient as will the skewed wing-tip flap.

In comparing the hinge-moment coefficients of figure 15, it should be noted that the hinge-moment dimensional constant $b_f\overline{c}_f^2$ is 1.825 times as great for the skewed wing-tip flap as for the constant-chord flap. The hinge-moment coefficients of the skewed wing-tip flap are little affected by Mach number, while the hinge moments of the constant-chord flap reverse at the higher Mach numbers. At all Mach numbers, the magnitude of the hinge moments is many times greater for the skewed wing-tip flap than for the constant-chord flap. The large values of hinge-moment coefficient required to balance the triangular wing with the skewed wing-tip flap are always negative and are primarily the result of the large negative value of $\partial C_h/\partial C_L$. It is thus indicated that the hinge moments could be reduced in magnitude if the moment center of the wing were shifted forward. The skewed wing-tip flap deflection and hinge-moment coefficient required to balance the triangular wing about the 0.25 point of the M.A.C. and the 0.10 point of the M.A.C. are compared in figure 16. The forward location of the center of moments results in a large reduction of the hinge moments required for balance; however, due to the large static stability the flap would be ineffective in balancing the airplane to even a moderate lift coefficient.

APPLICATION OF DATA

The data of this report have been applied to the calculation of the level-flight characteristics of a hypothetical tailless airplane equipped with a triangular wing geometrically similar to the model wing. The dimensions of the airplane were assumed to be as follows:

Wing area	500 sq ft
Wing span	31.91 ft
Control-surface area	102.25 sq ft
Control-hinge moment	$612.6C_{h_q}$ ft-lb
Center of gravity	0.32 M.A.C.

With the exception of the type of control surface and the absence of a fuselage, the hypothetical airplane is identical with that employed in the calculations of reference 1. Since the data of reference 1 indicate that the addition of the body caused only minor changes in the wing characteristics, the results of these calculations can be compared directly with figure 29 of reference 1.

The lift coefficient, flap deflection, and hinge moment required for level flight at an altitude of 30,000 feet are presented in figure 17 for wing loadings of 40, 60, and 80 pounds per square foot. Stick-fixed stability is seen to exist at all Mach numbers but the control forces are extremely large and, if tabs are used to trim the airplane, stick-free instability will exist at all subsonic Mach numbers. Calculations indicate the stick-free neutral point to be at about 0.07 M.A.C. but, as previously explained, excessive flap deflections would be required to balance or maneuver the airplane with this center-of-gravity position.

The following table compares the values of the untrimmed hinge moments of a skewed wing-tip flap and the constant-chord flap for level flight with a wing loading of 60 pounds per square foot:

Mach number	Hinge moment	
	Skewed wing-tip flap	Constant-chord flap
0.60	-16,000 ft-lb	-2,000 ft-lb
.80	-19,000 ft-lb	-2,400 ft-lb
.90	-19,000 ft-lb	-2,000 ft-lb
.95	-21,000 ft-lb	-1,000 ft-lb

At these Mach numbers, the superiority of the constant-chord flap is clearly demonstrated.

CONCLUSIONS

The following conclusions have been drawn from the results of tests of a triangular wing with a skewed wing-tip flap and from the comparison of a skewed wing-tip flap with a constant-chord flap of the same area on a triangular wing:

1. The flap was effective in producing changes in lift and pitching moment at Mach numbers up to 0.95.

2. Increasing the Mach number from 0.30 to 0.95 resulted in increases in the lift effectiveness and the pitching-moment effectiveness of 20 percent and 40 percent, respectively.

3. The rate of change of hinge-moment coefficient with angle of attack was −0.029 at low speeds and increased negatively to −0.040 at a Mach number of 0.95.

4. The rate of change of hinge-moment coefficient with flap deflection was −0.008 at low speeds and increased negatively to −0.010 at a Mach number of 0.95.

5. The skewed wing-tip flap was less affected by compressibility than the constant-chord flap.

6. The effectiveness of the skewed wing-tip flap as a longitudinal control was indicated to be about one-quarter as great as the effectiveness of the constant-chord flap.

7. The control forces for level flight or accelerated flight with the skewed wing-tip flap and the center of gravity at 32 percent of the mean aerodynamic chord would be many times greater than the control forces with the constant-chord flap.

8. At low speeds, the stick-free neutral point with the skewed wing-tip flap was about 18 percent of the mean aerodynamic chord ahead of the stick-free neutral point with the constant-chord flap.

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REFERENCES

1. Stephenson, Jack D., and Amuedo, Arthur R.: Tests of a Triangular Wing of Aspect Ratio 2 in the Ames 12-Foot Pressure Wind Tunnel. II – The Effectiveness and Hinge Moments of a Constant-Chord Plain Flap. NACA RM No. A8E03, 1948.

2. Edwards, George G., and Stephenson, Jack D.: Tests of a Triangular Wing of Aspect Ratio 2 in the Ames 12-Foot Pressure Wind Tunnel. I – The Effects of Reynolds Number and Mach Number on the Aerodynamic Characteristics of the Wing with Flap Undeflected. NACA RM No. A7K05, 1948.

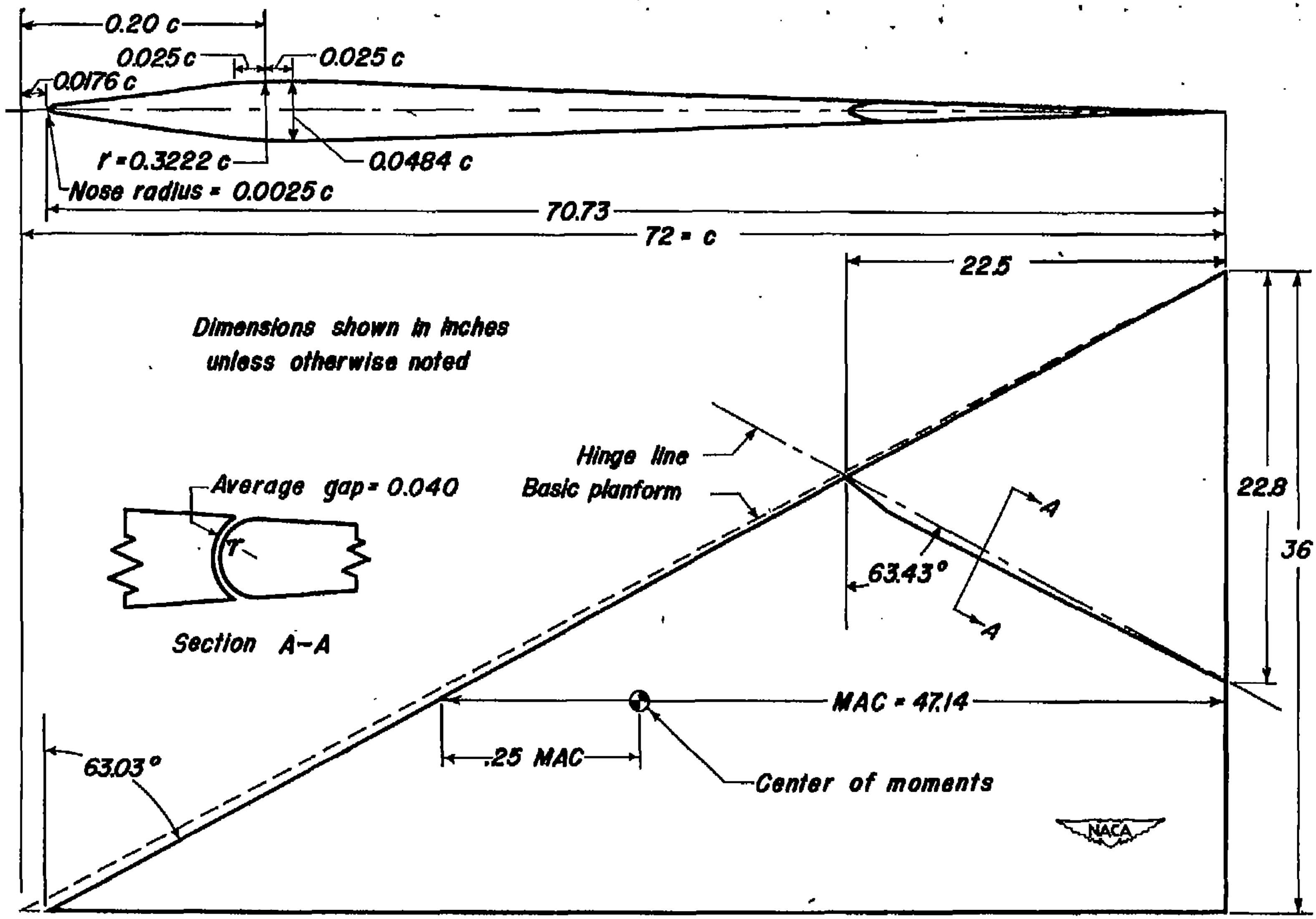


Figure 1.– Semispan model of a triangular wing of aspect ratio 2 with a skewed wing-tip flap.

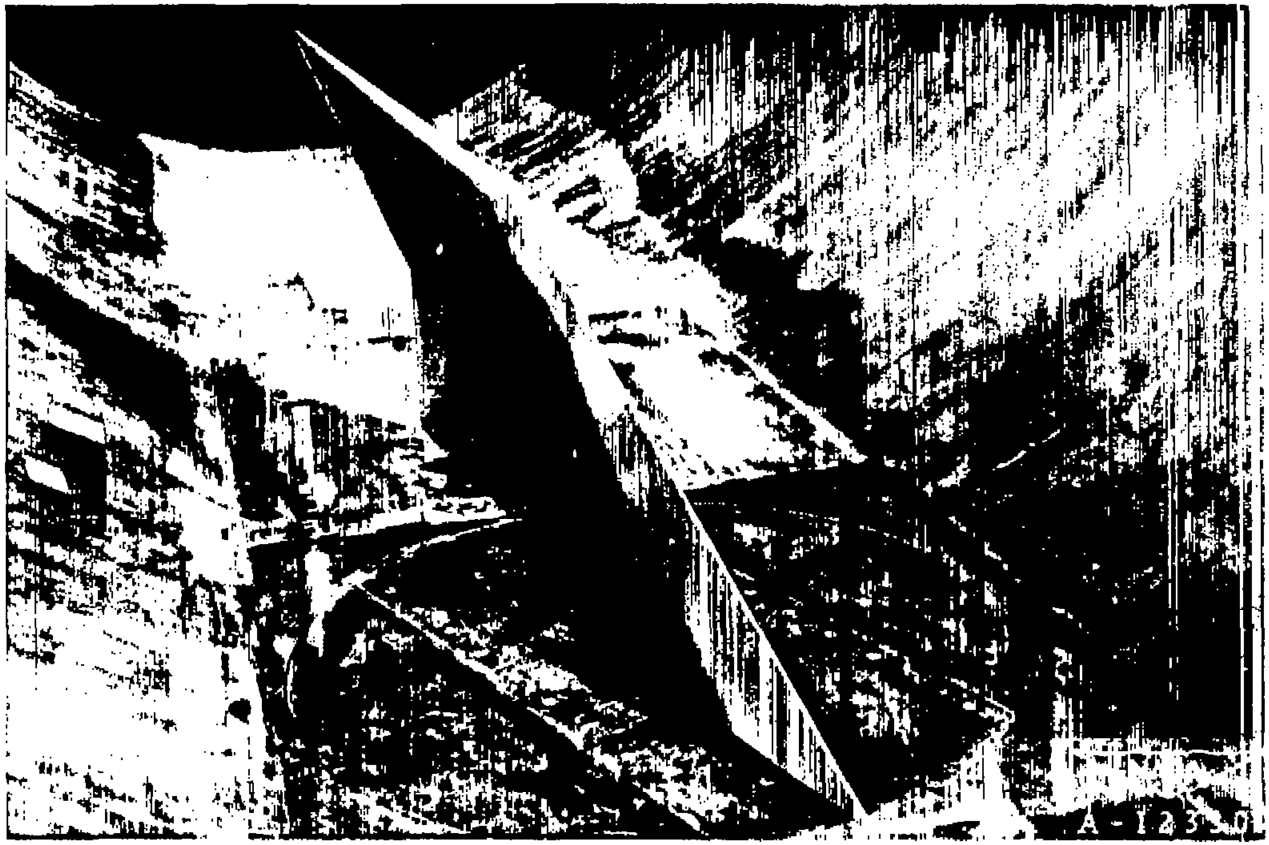
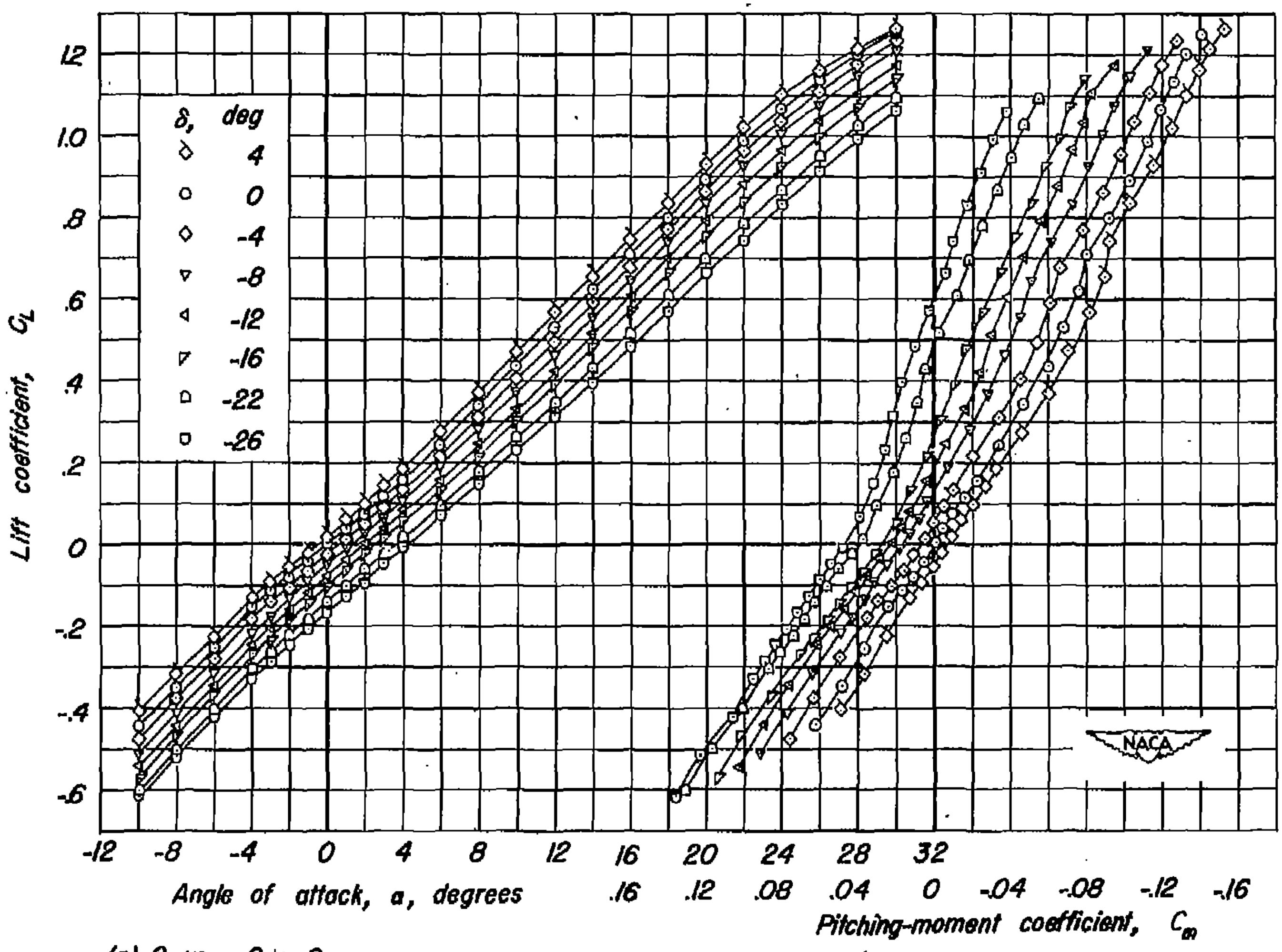
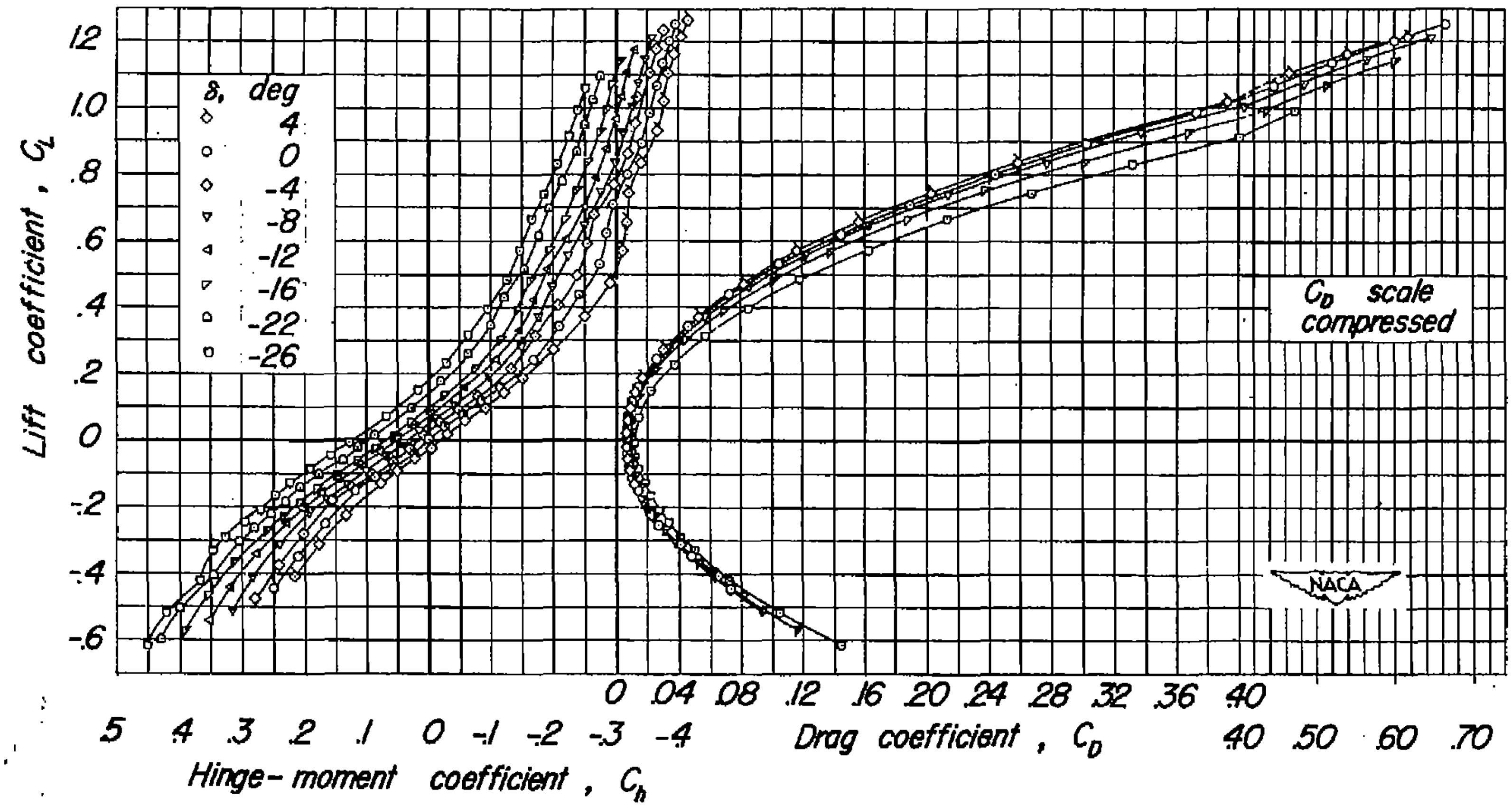


Figure 2.– The semispan triangular wing, with a deflected skewed wing-tip flap mounted in the Ames 12–foot pressure wind tunnel.



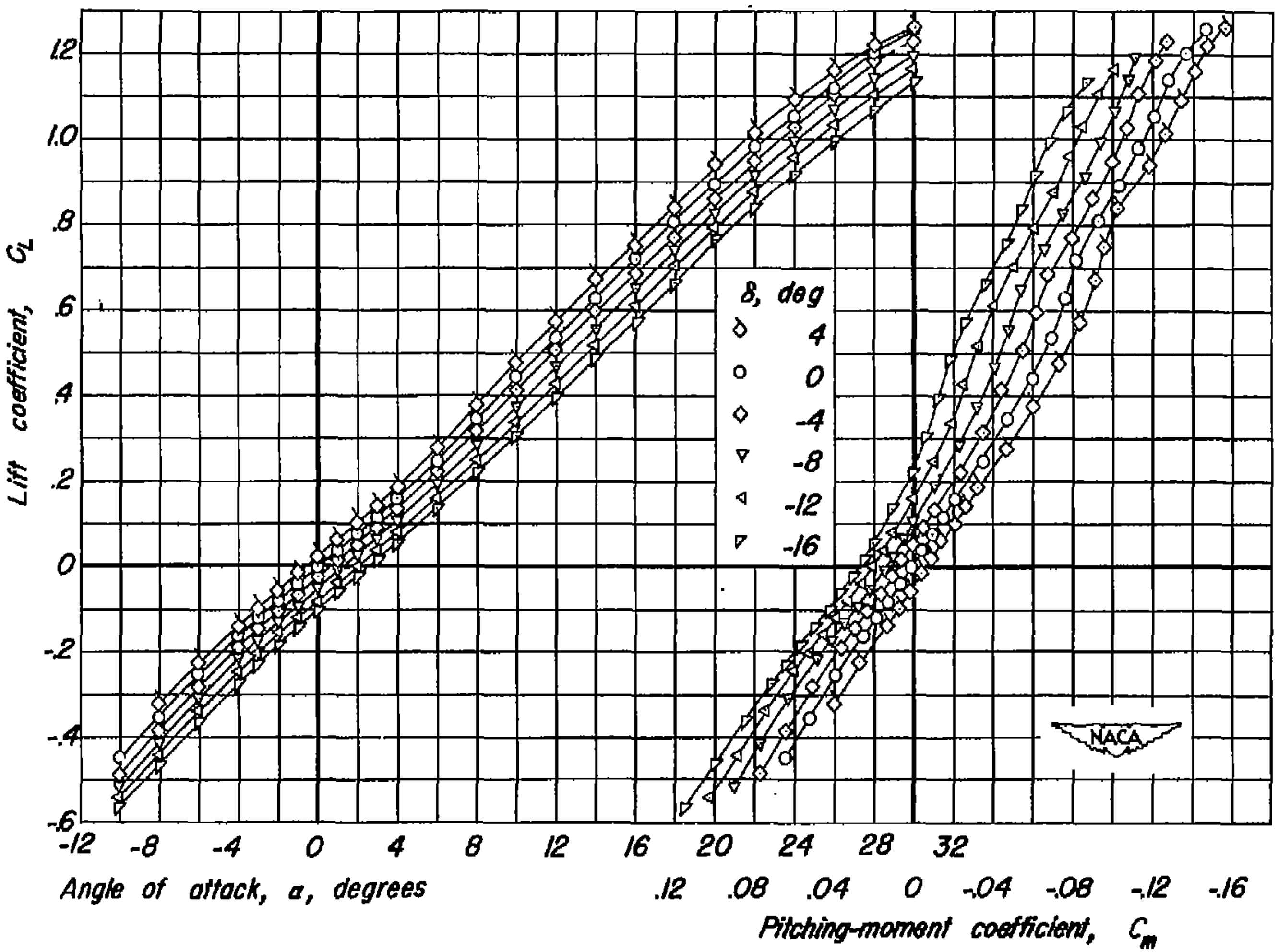
(a) C_L vs α, C_L vs C_m

Figure 3.–The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.180; R, 5,000,000.



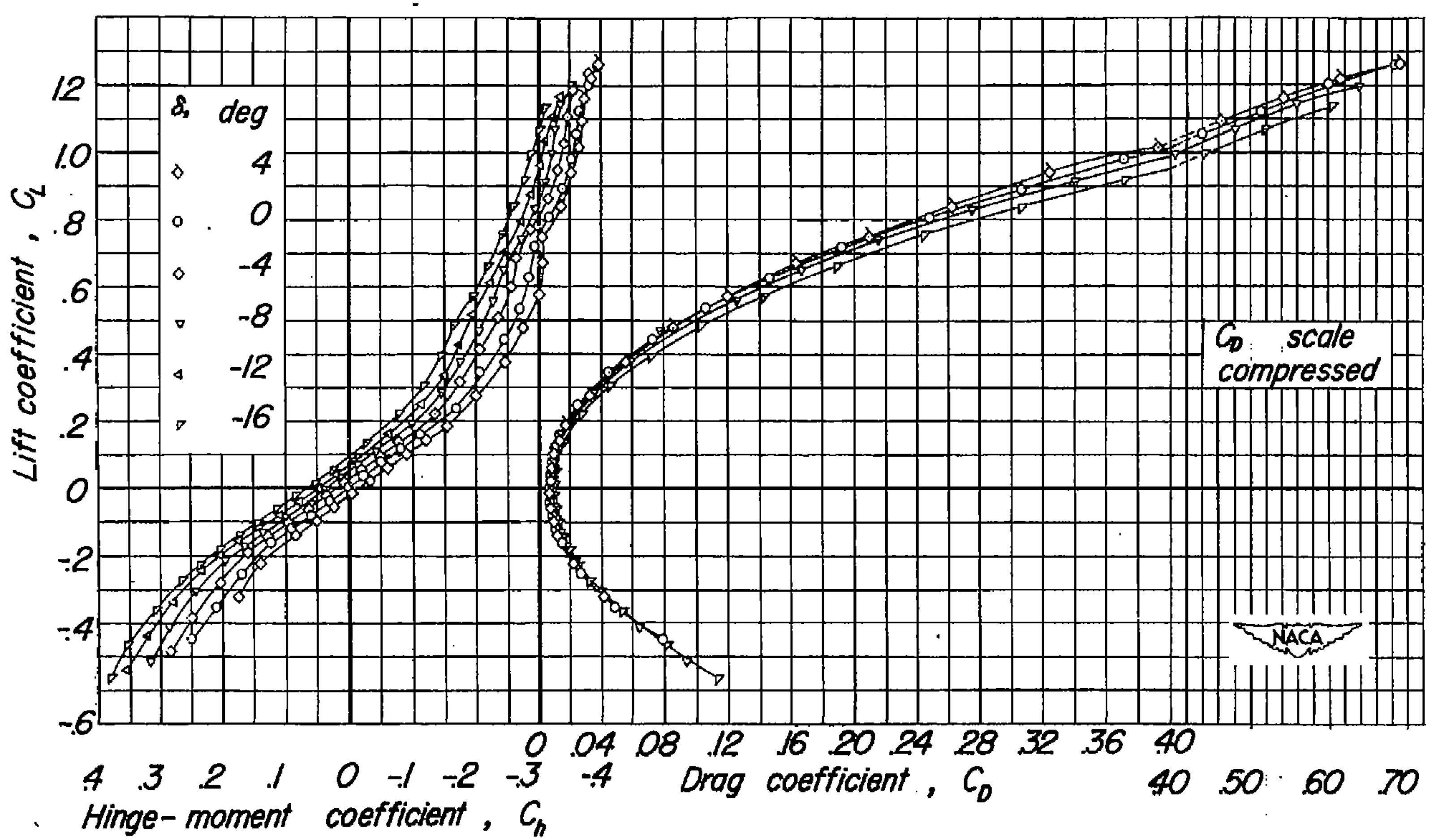
(b) C_L vs C_h, C_L vs C_D

Figure 3.– Concluded.



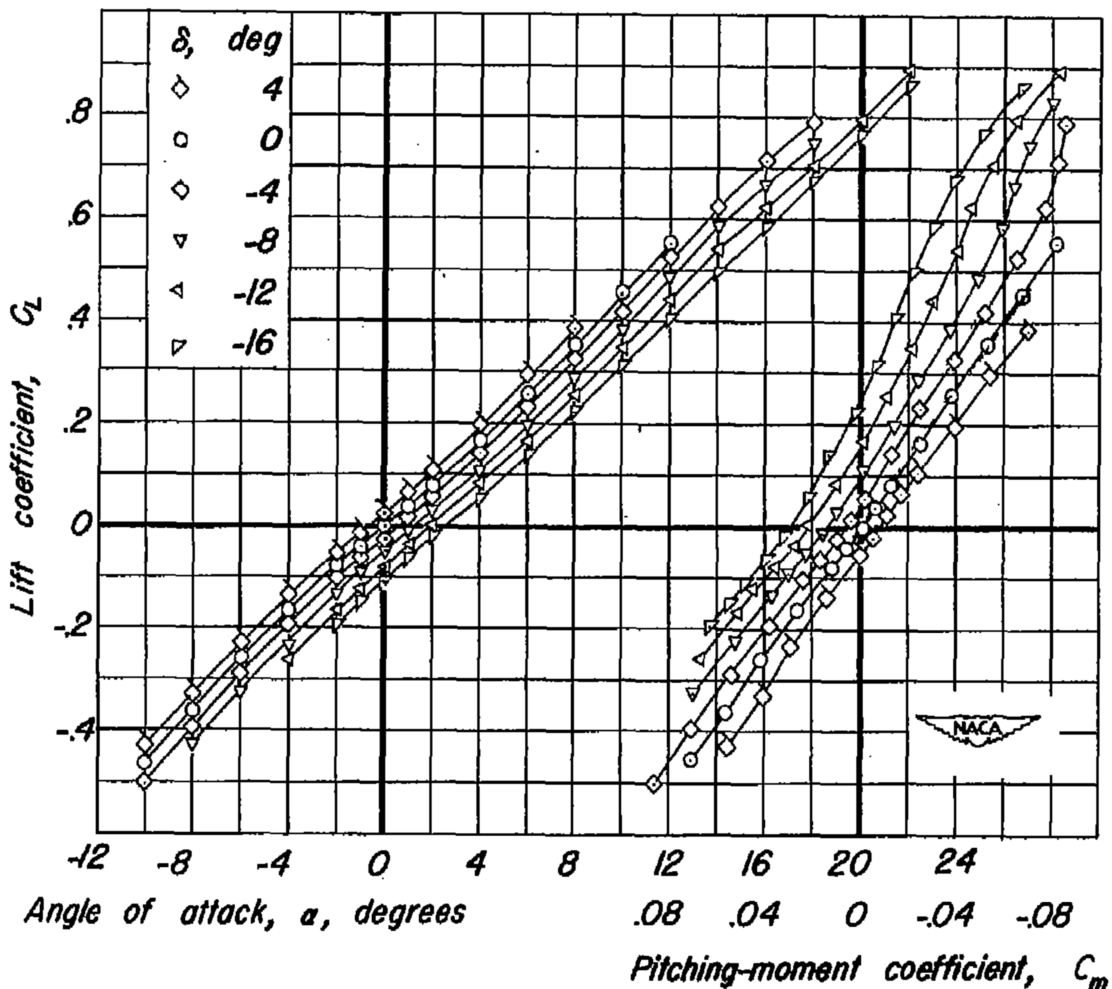
(a) C_L vs α, C_L vs C_D

Figure 4.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.300; R, 3,200,000.



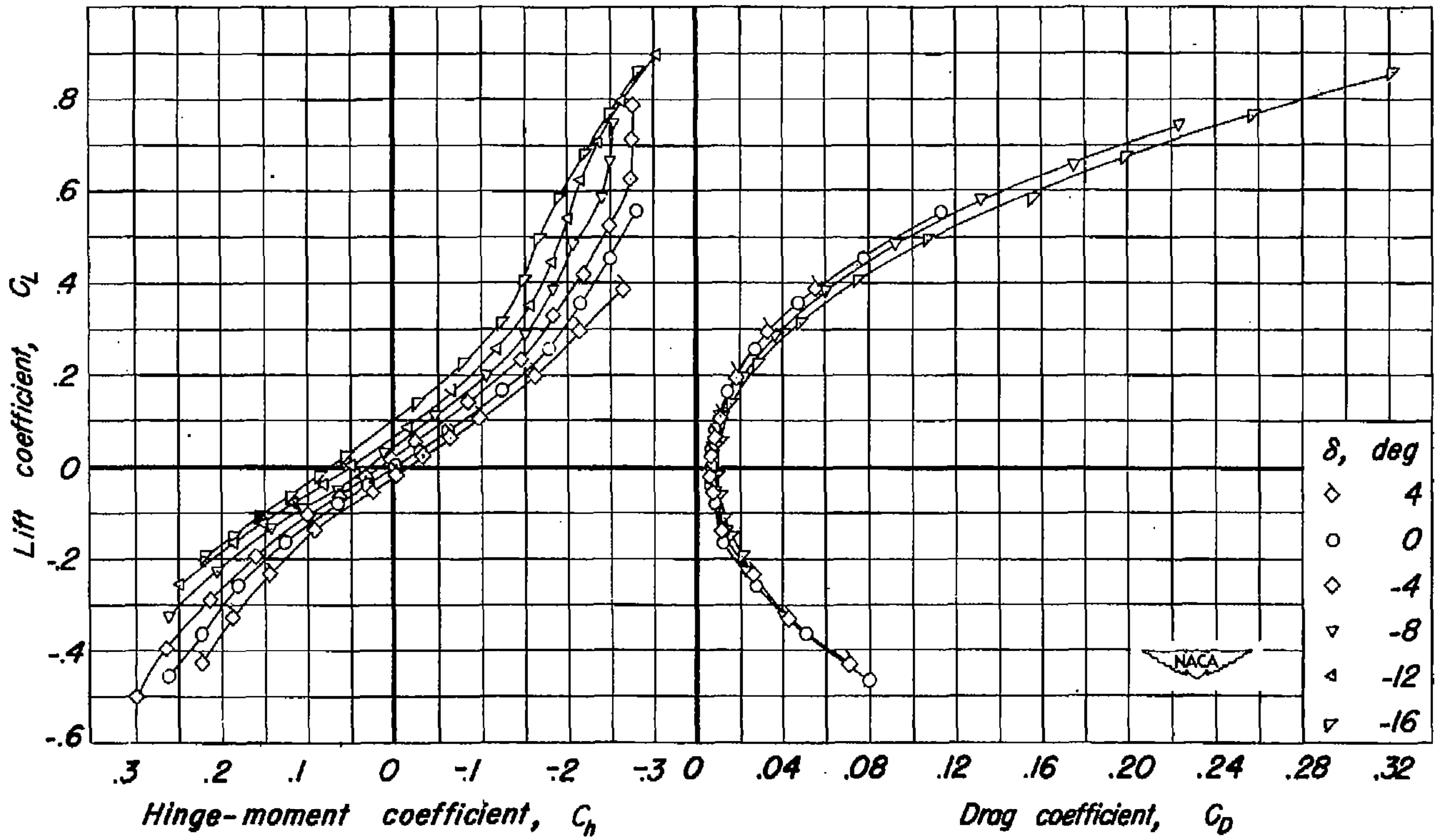
(b) C_L vs C_h, C_L vs C_D

Figure 4.– Concluded.



(a) C_L vs α, C_L vs C_m

Figure 5.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.600; R, 3,200,000.



(b) C_L vs C_h, C_L vs C_D

Figure 5.— Concluded.

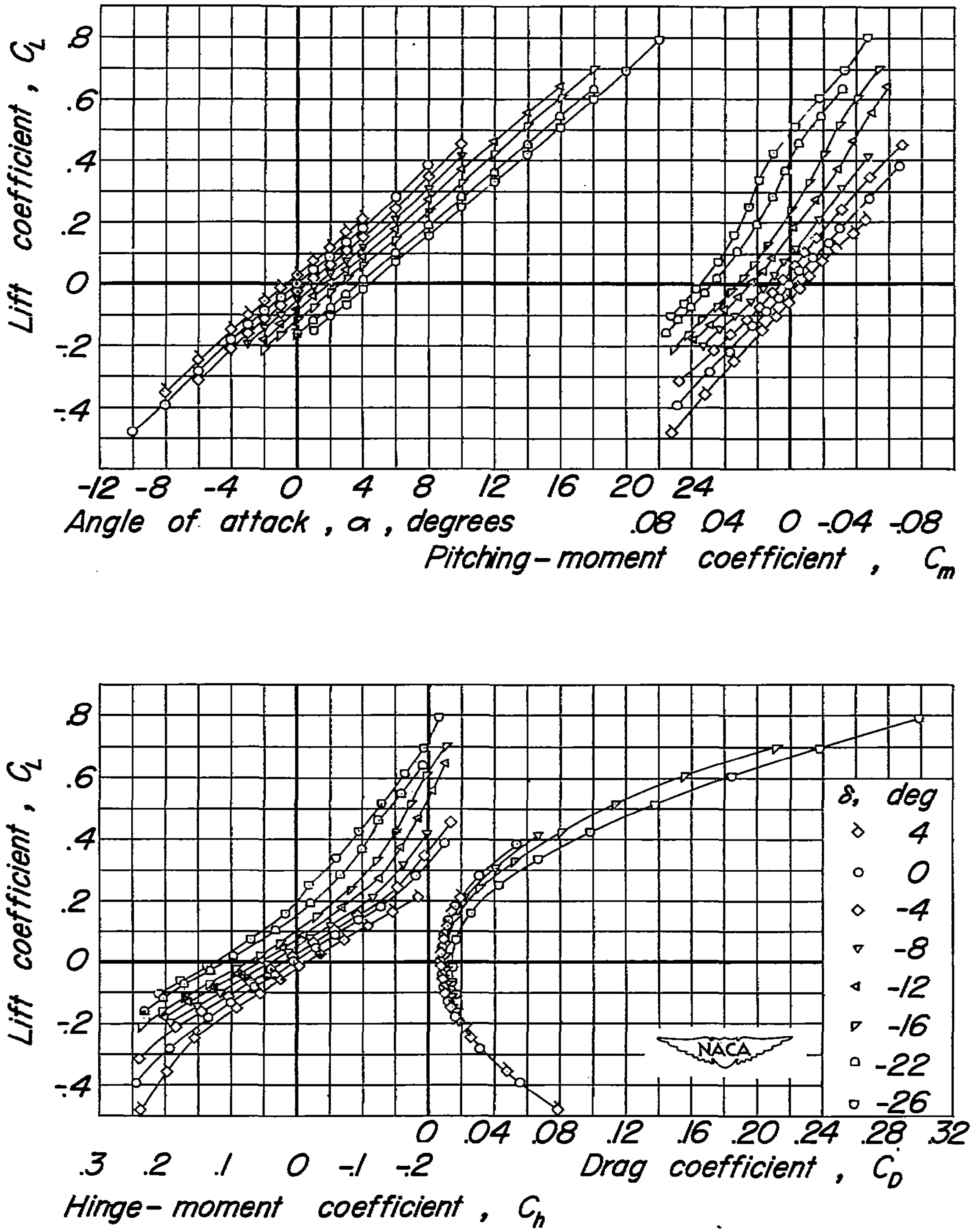


Figure 6.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.800; R, 3,200,000.

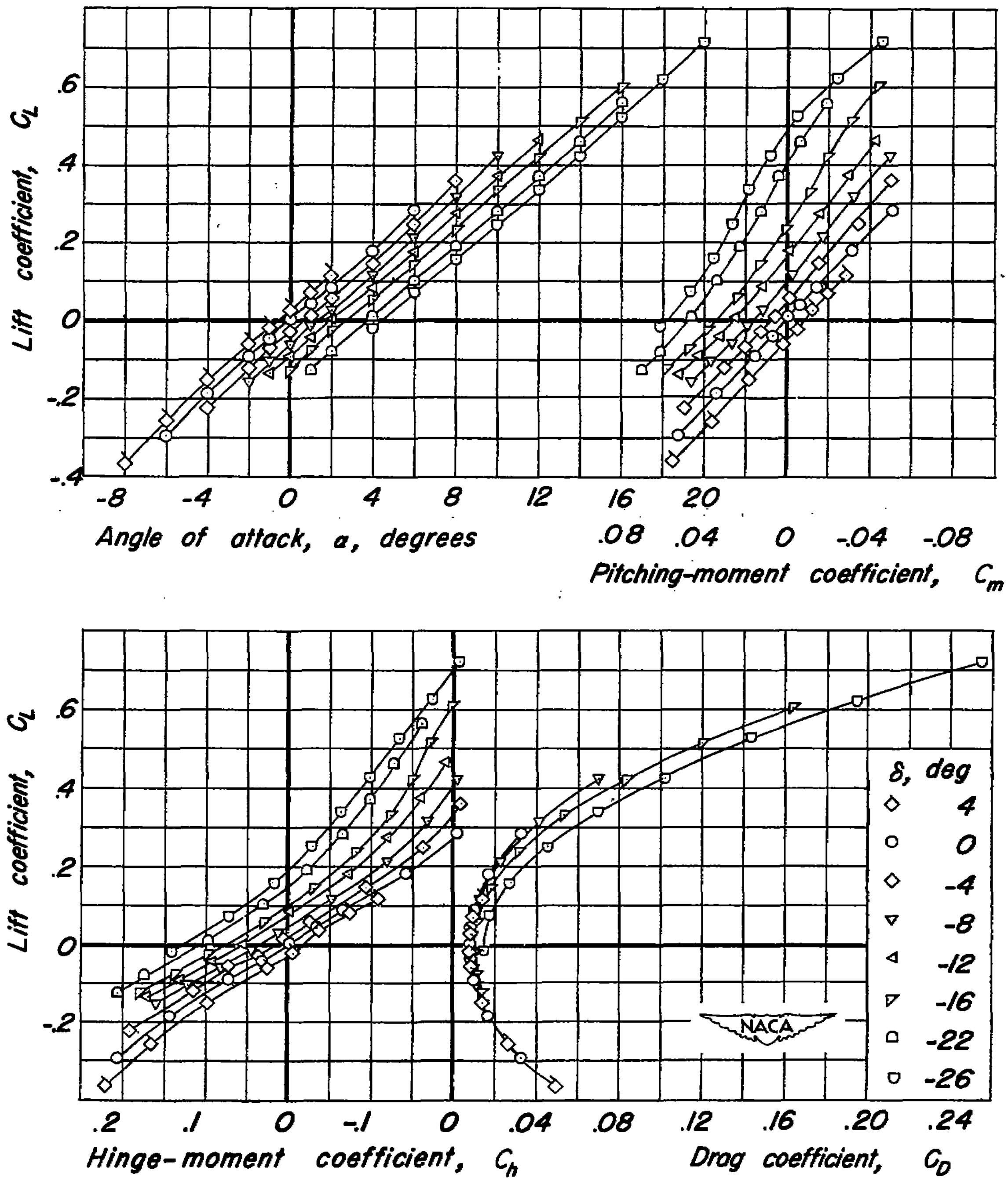


Figure 7.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.850; R, 3,200,000.

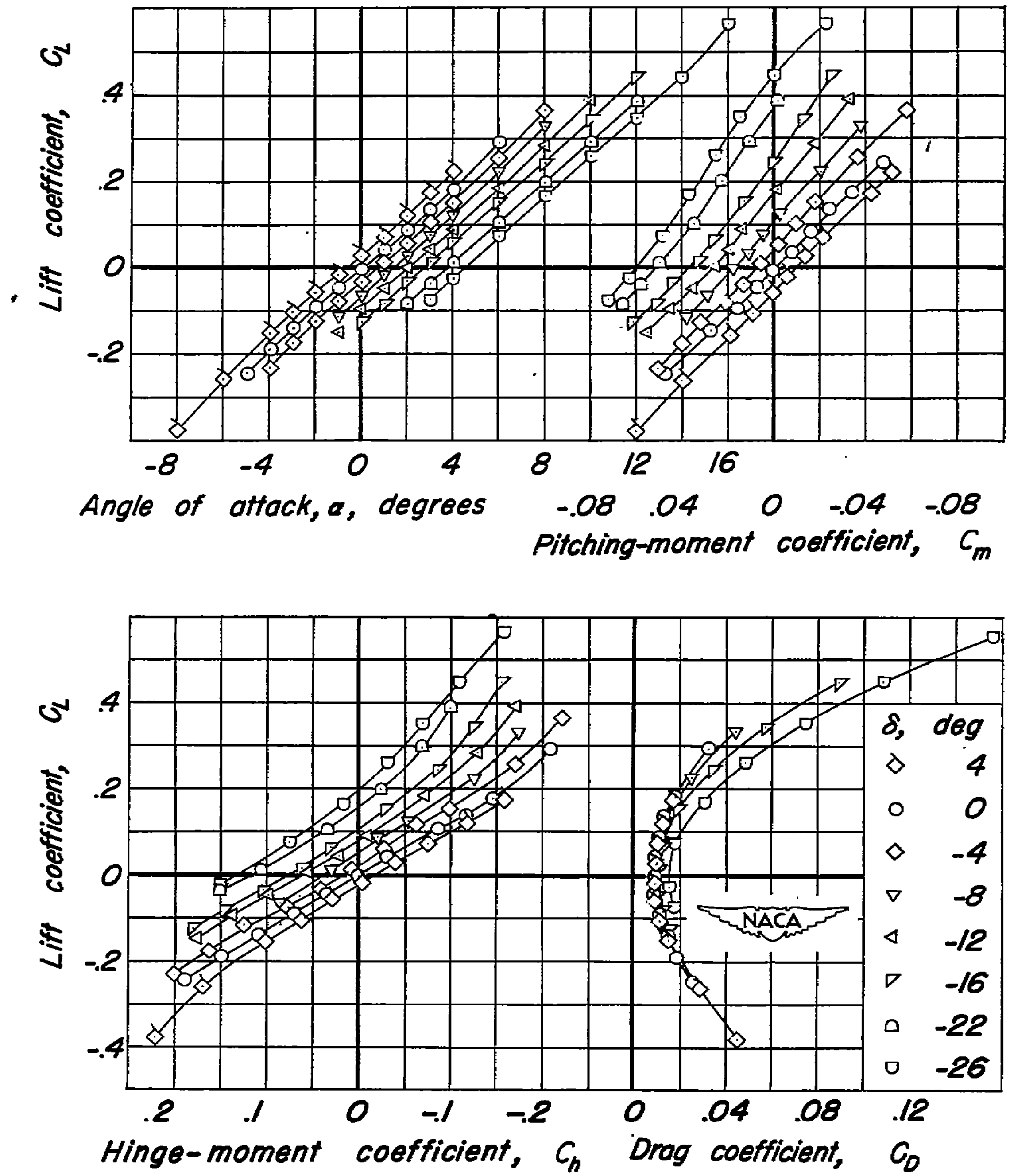


Figure 8.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.900; R, 3,200,000.

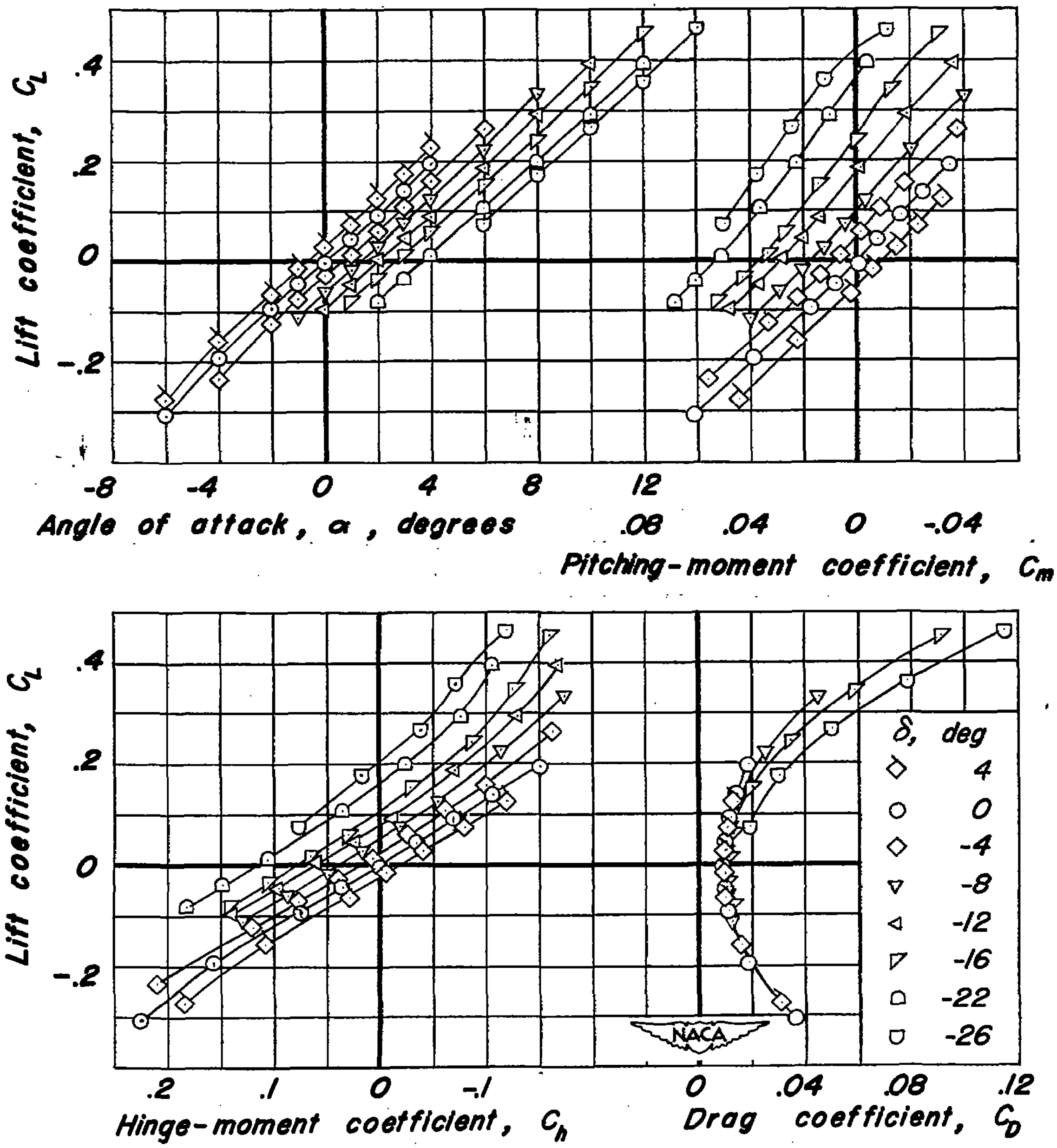
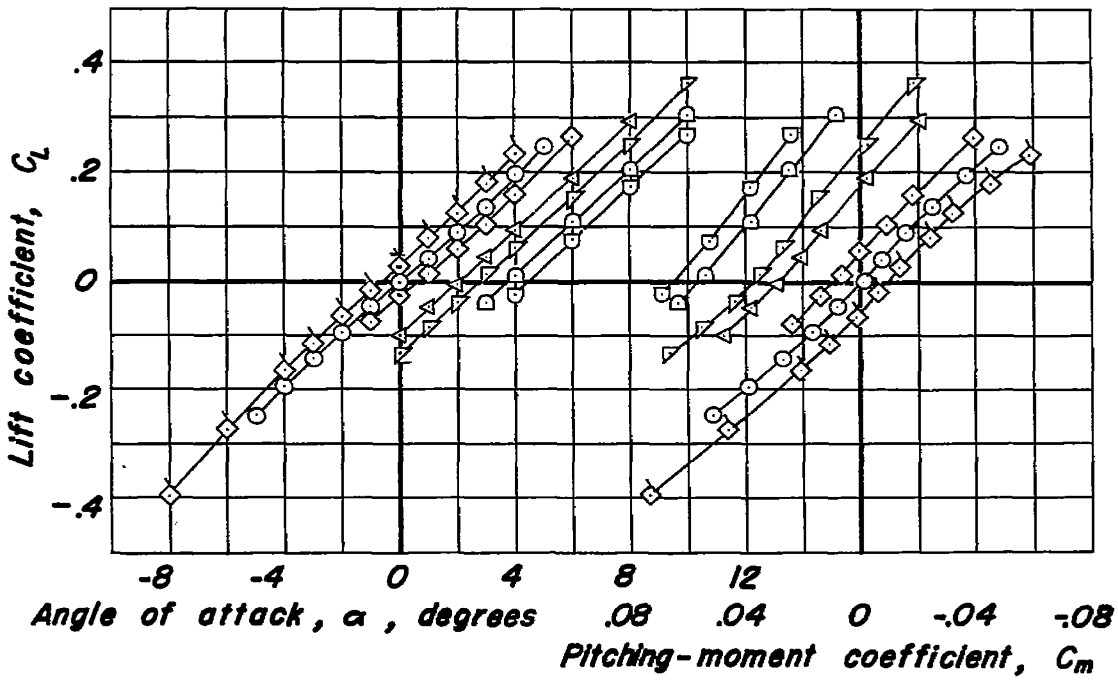


Figure 9.— The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.925; R, 3,200,000.



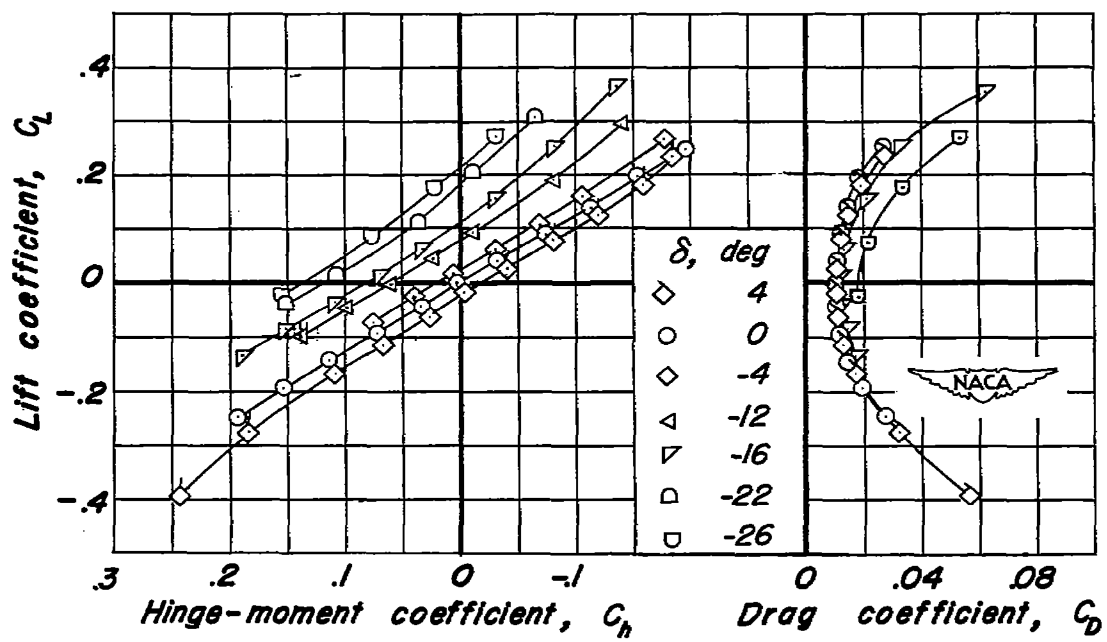


Figure 10.– The aerodynamic characteristics of a triangular wing for various flap angles. M, 0.950; R, 3,200,000.

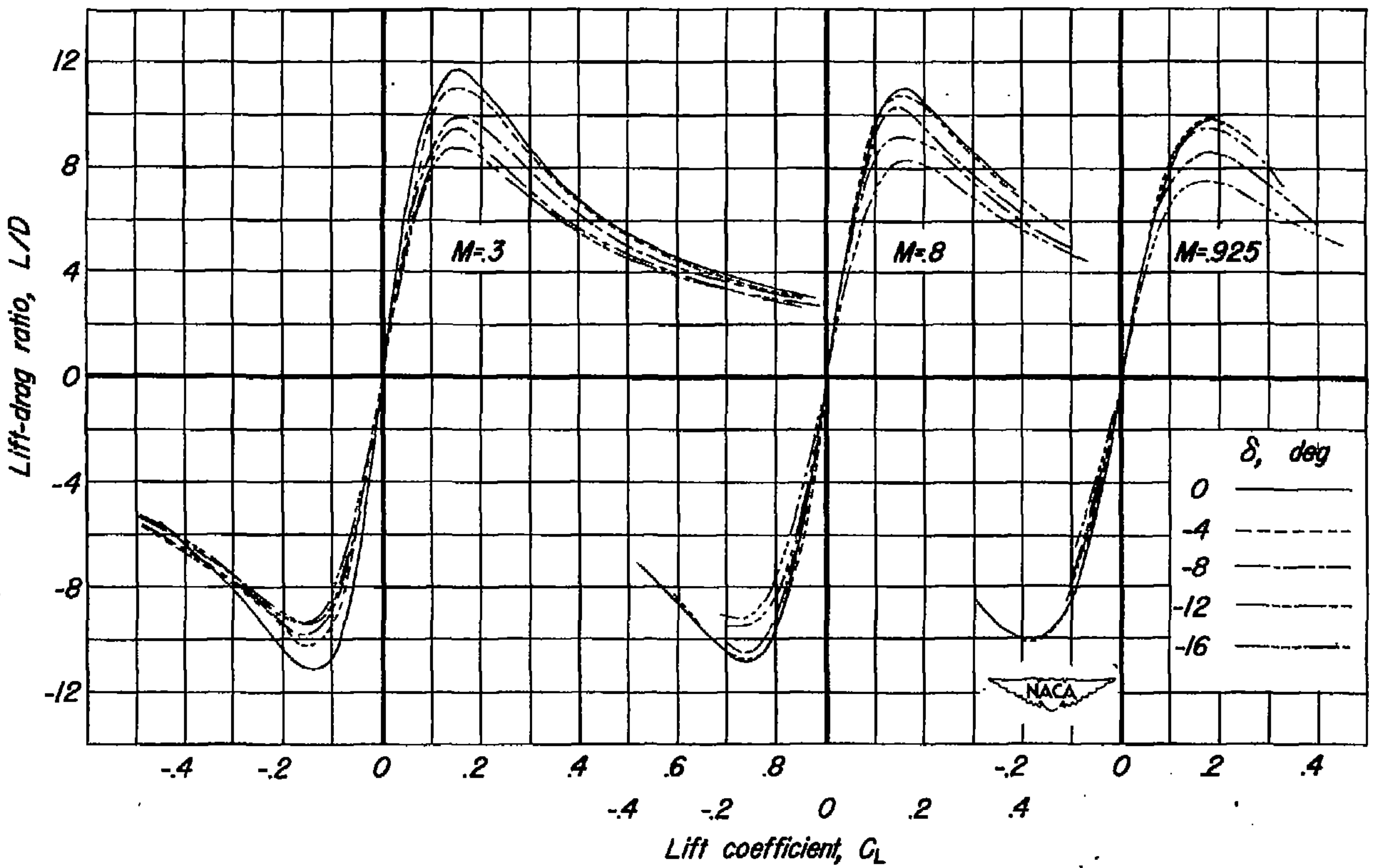


Figure 11 - The variation of lift-drag ratio with lift coefficient for a triangular wing having a skewed wing-tip flap at several Mach numbers. R, 3,200,000.

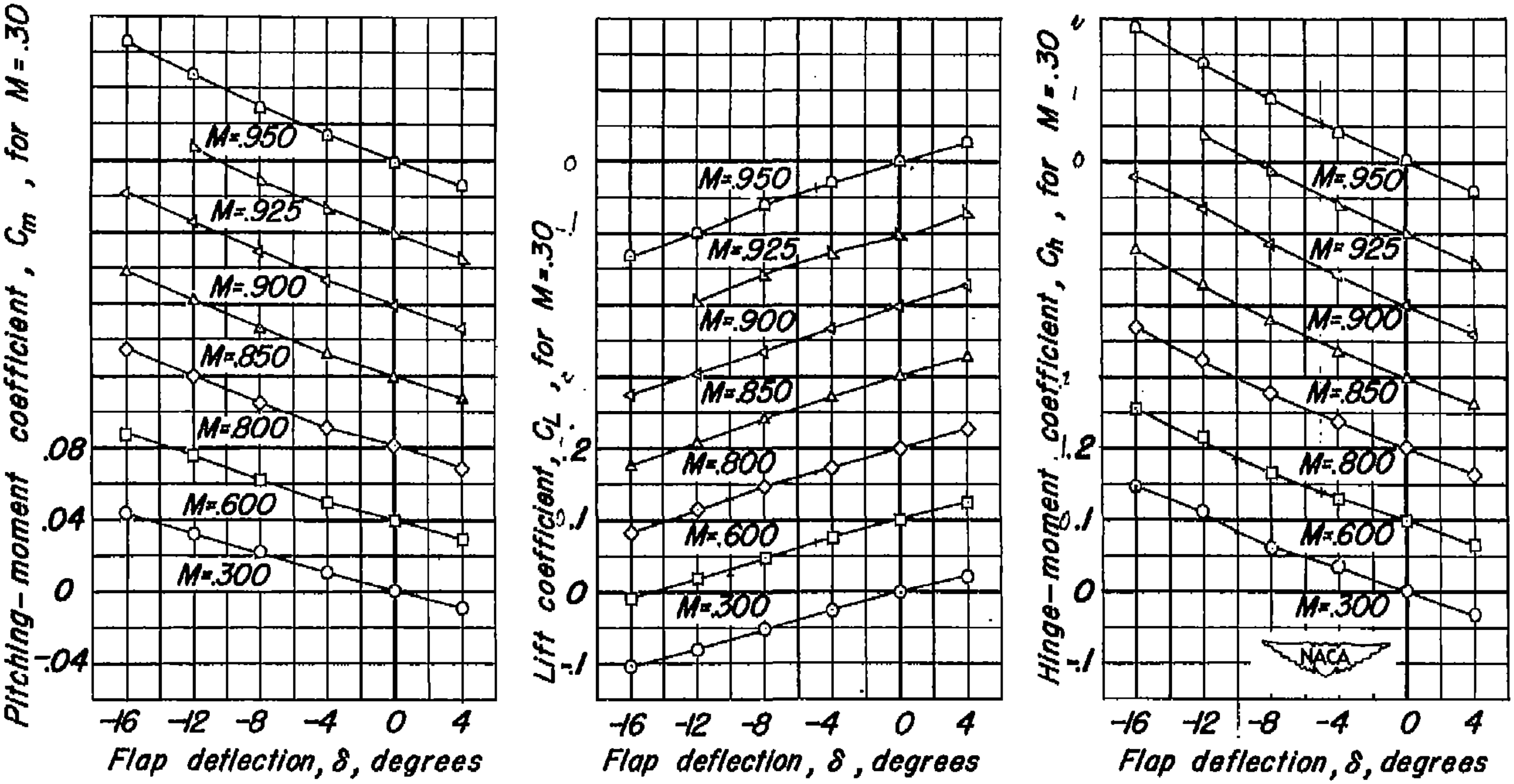


Figure 12.– The variations of lift coefficient, pitching-moment coefficient, and hinge-moment coefficient with flap deflection. α, 0°; R, 3,200,000.

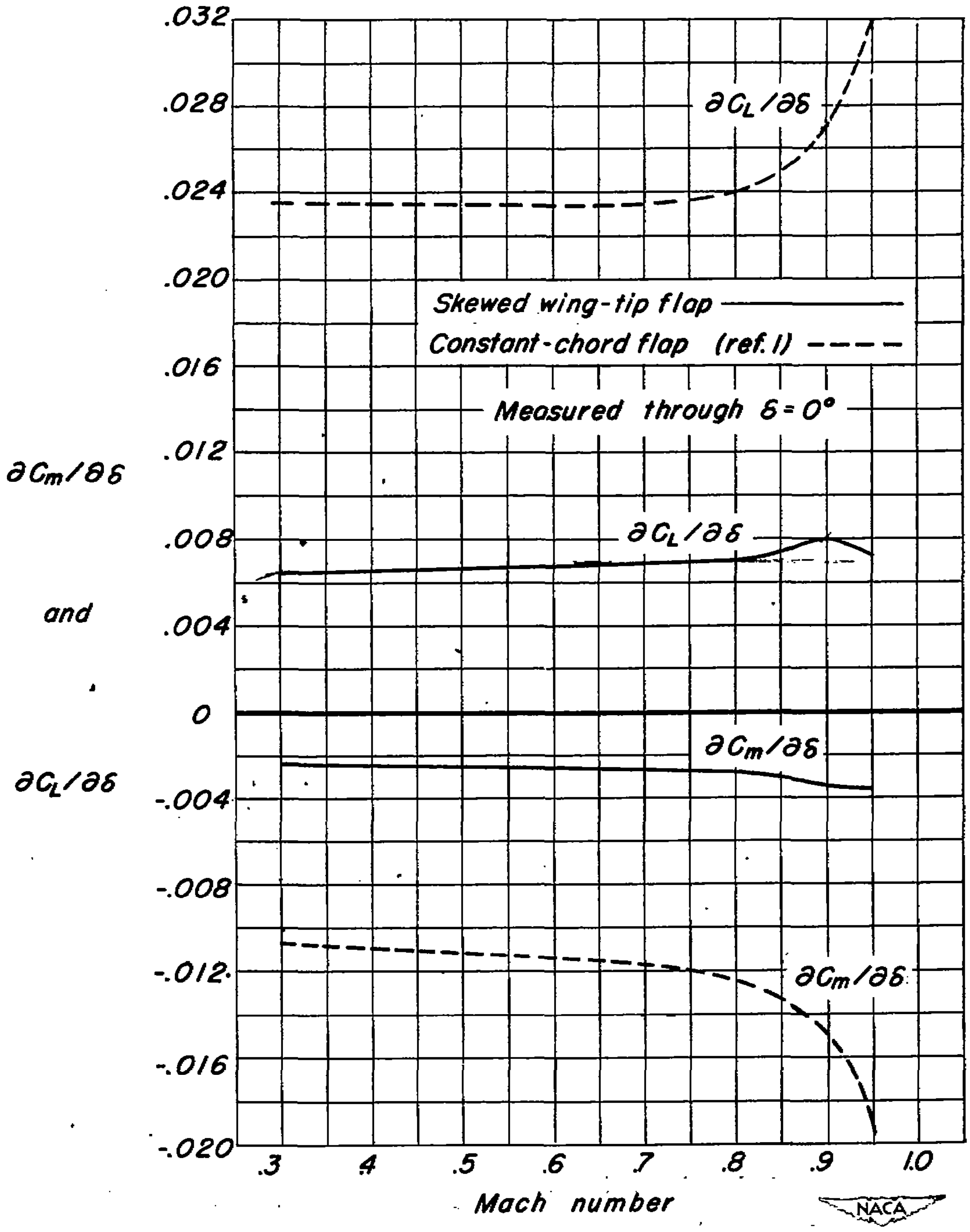


Figure 13.– The variation of the effectiveness of a skewed wing-tip flap and a constant-chord flap with Mach number on a triangular wing model. α, 0°.

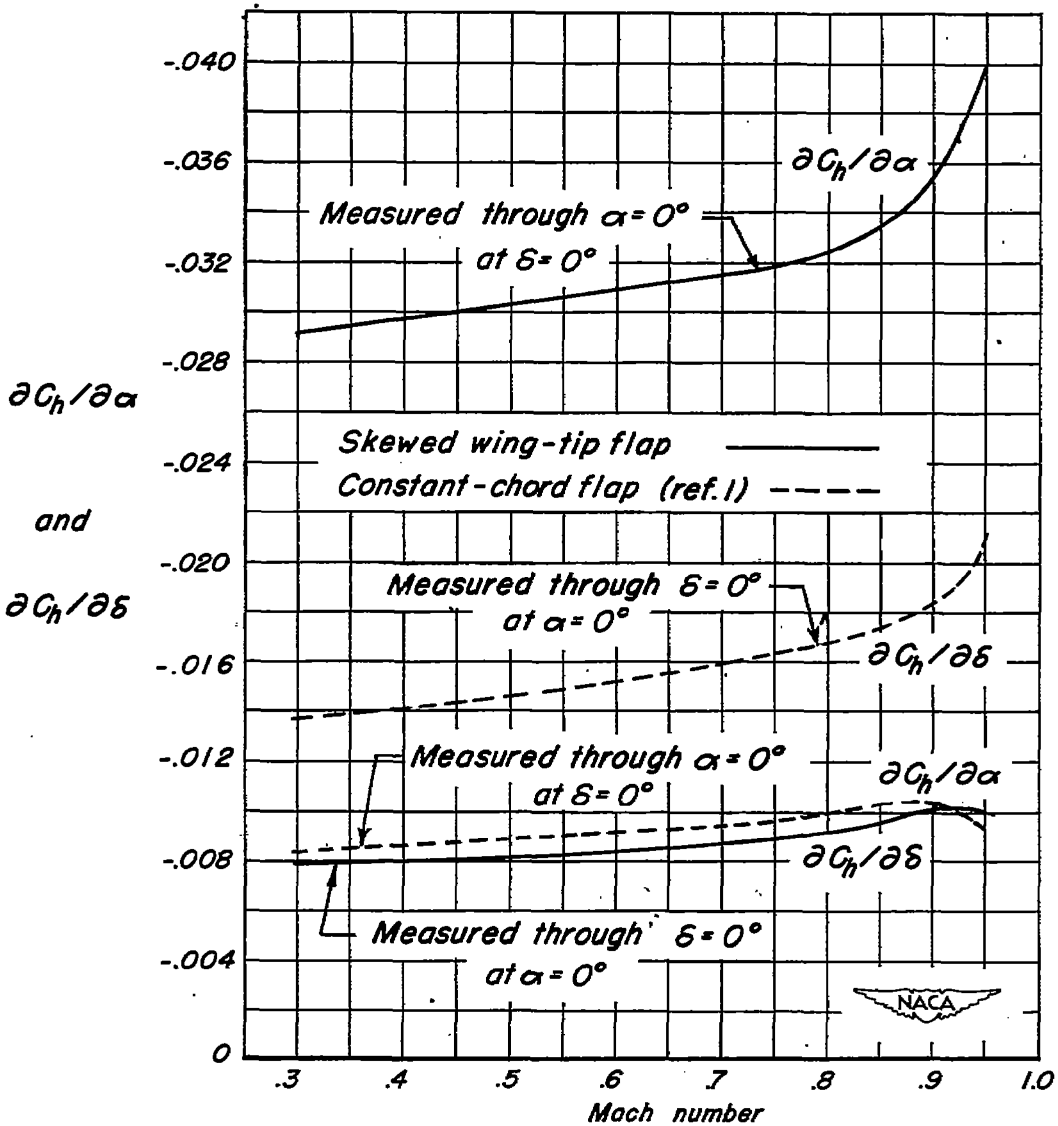


Figure 14.- The variation of the hinge-moment characteristics of a skewed wing-tip flap and a constant-chord flap with Mach number on a triangular wing model.

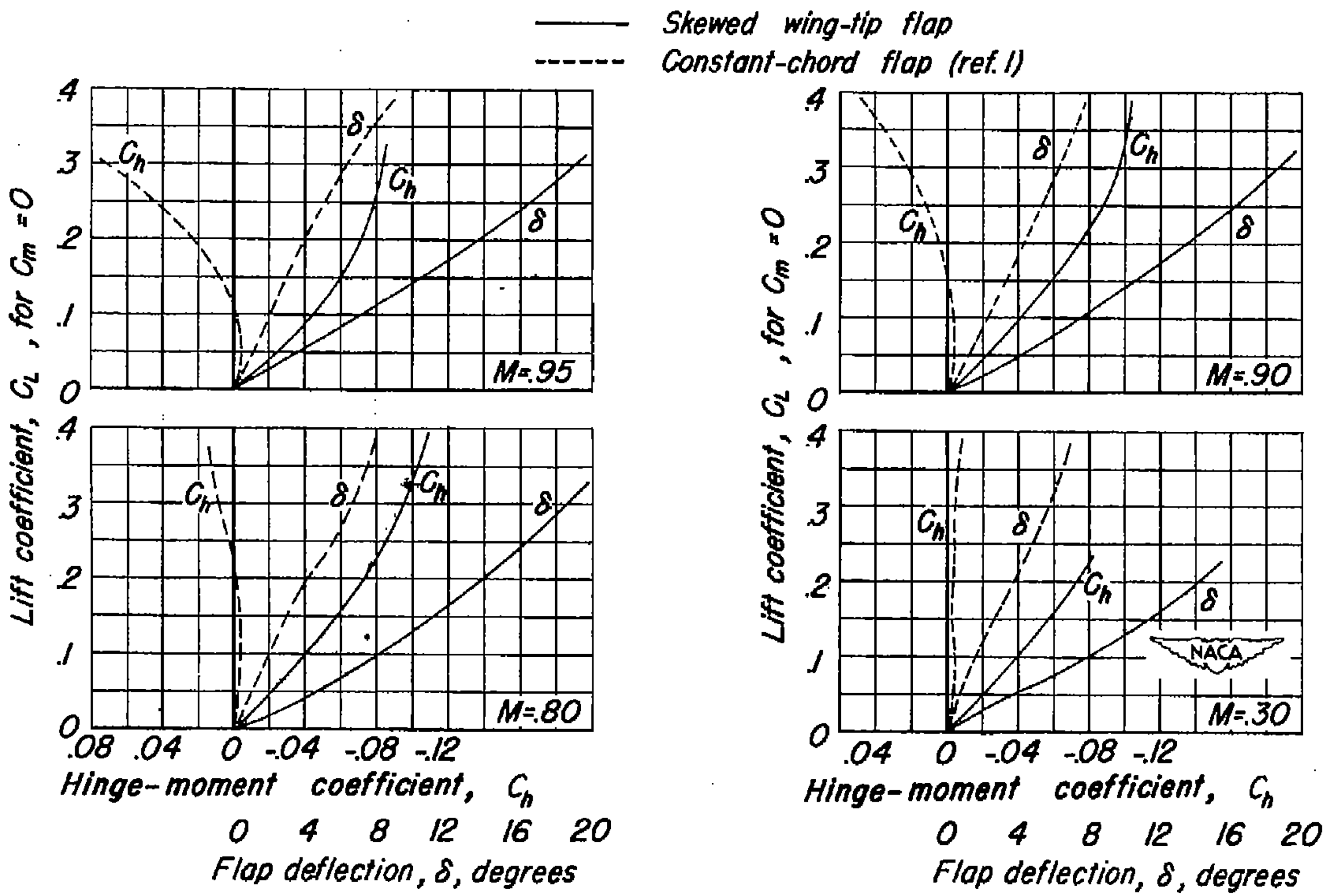


Figure 15.– The variation of lift coefficient at zero pitching moment with flap deflection and hinge-moment coefficient for a skewed wing-tip flap and a constant-chord flap on a triangular wing with the moment center at 0.25 MAC.

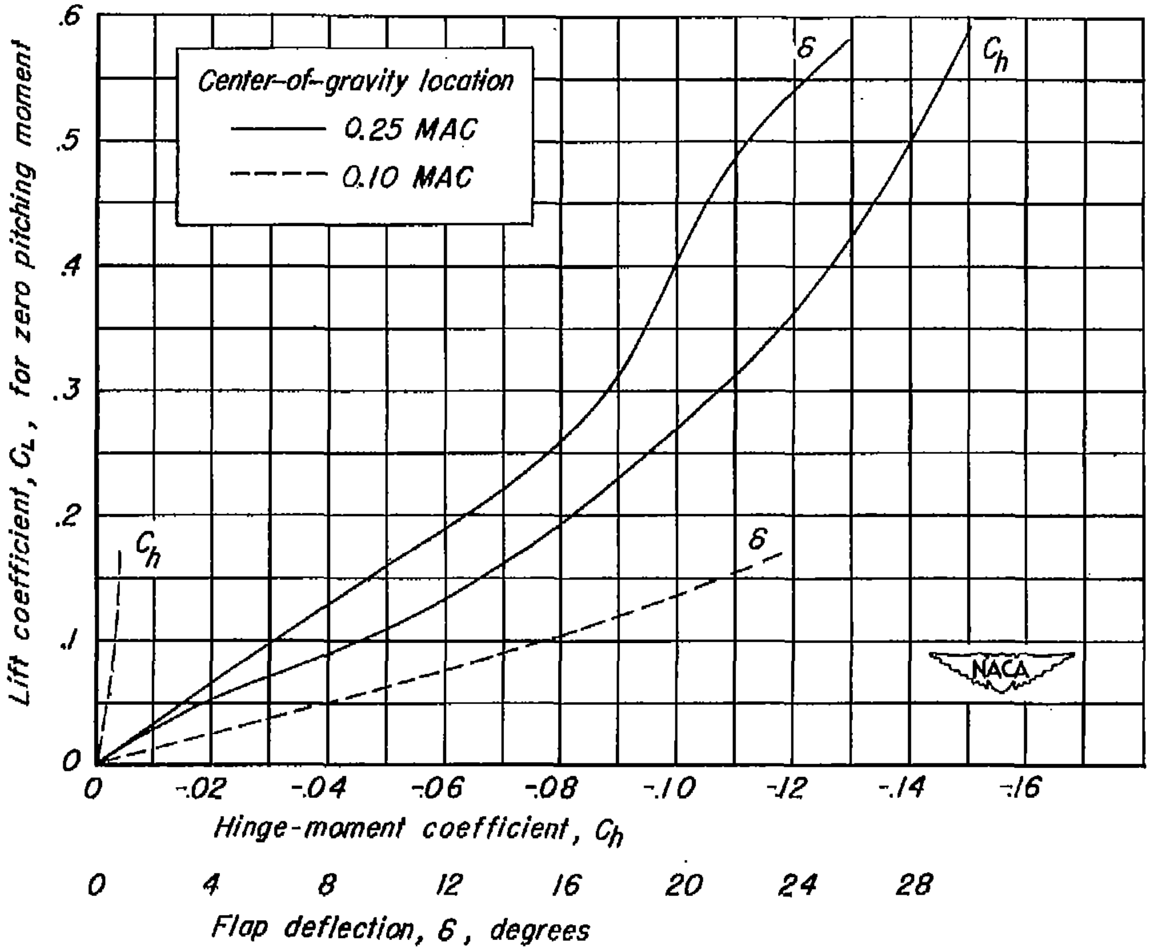


Figure 16.- The variation of lift coefficient at zero pitching moment with flap deflection and hinge-moment coefficient for a skewed wing-tip flap on a triangular wing for two different moment centers. M, 0.180; R, 5,000,000.

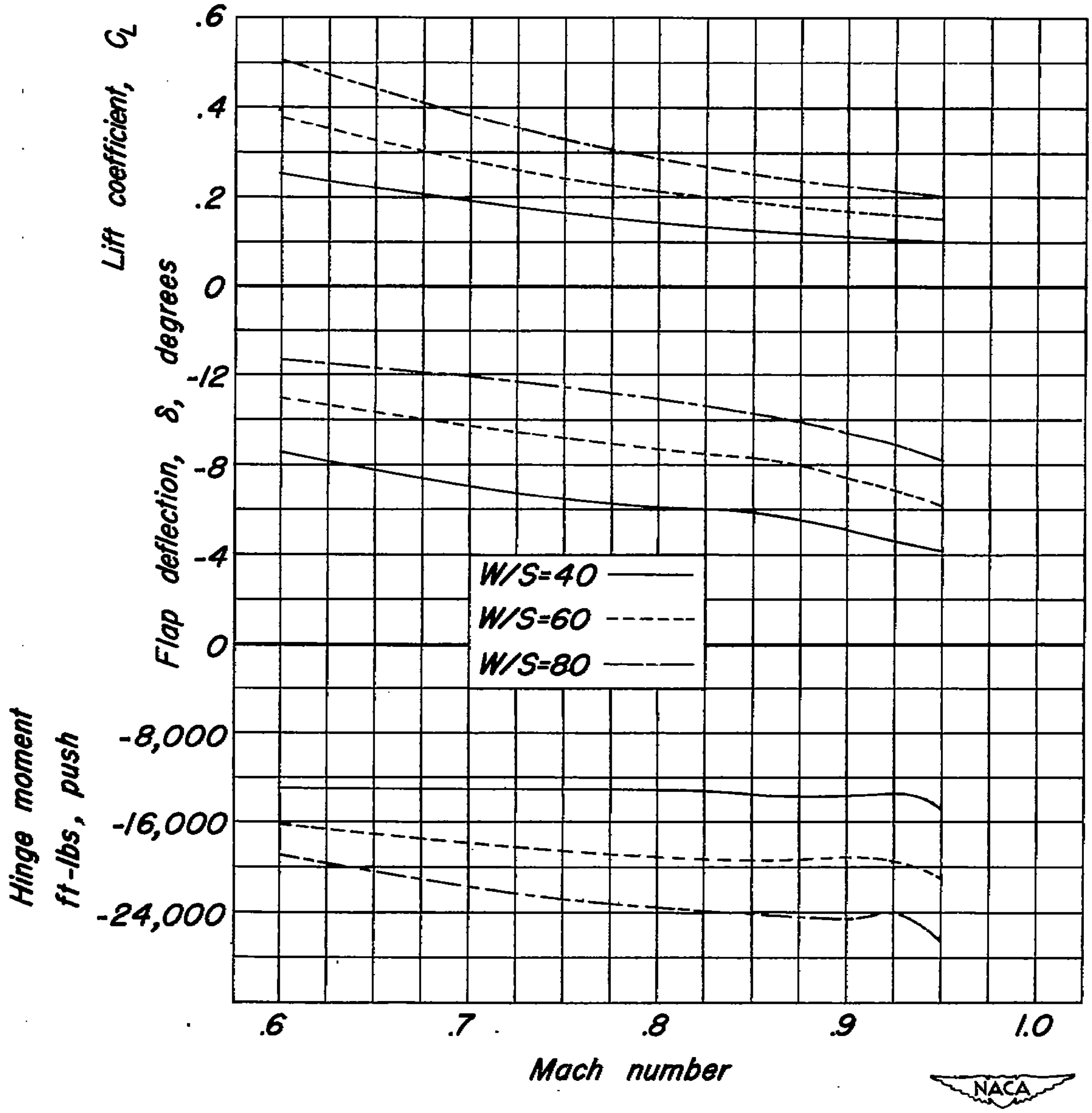


Figure 17.– The variations of lift coefficient, hinge moment, and flap deflection with Mach number for level flight of a triangular winged aircraft at 30,000 feet altitude. Wing area, 500 sq ft, c.g. at 0.32 MAC.